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The solar diurnal variation of cosmic ray intensity during the periods of the different polarities of the solar polar magnetic fields

N K Sharma, S S Dhal, K P Singh and R S Yadav*
Post Graduate Department of Physics, D P B S (P G) College, Anupshahar-202 390, Bulandshahar, Uttar Pradesh, India

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Abstract : Using the neutron monitor data of Deep-River (Rc = 1.02 GV) the behaviour of the solar diurnal anisotropy of the galactic cosmic rays has been investigated for three different periods · 1964–68 ($\mp$), when the northern solar polar magnetic field was negative, 1972–79 ($\pm$), when it became positive and 1981–86 ($\mp$), when again the northern solar polar magnetic field became negative. It is found that the phase of the diurnal anisotropy shifts to earlier hours during the period 1972–79 ($\pm$) as compared to that for the period 1964–68 ($\mp$) and during 1981–86 ($\mp$), it again tends to shift towards the position observed in 1964–68 ($\mp$). This shows a 22 year periodicity in the phase of the diurnal anisotropy related with the 22 year solar magnetic cycle The phase shifts to earlier hours during 1972–79 ($\pm$) period can be explained by the drift model

Keywords : Cosmic ray intensity, Sun-polarity reversal

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1. Introduction

Various cosmic ray anisotropies are found to depend on the polarity of solar polar magnetic field which extends in the interplanetary space by the solar wind. The interplanetary magnetic field is assumed to be an archimedean spiral [1]; the senses of the spiral in the northern and southern hemispheres are opposite to each other, with the change in sense occurring at equatorial current sheet.

The solar diurnal variation of cosmic ray intensity was interpreted initially on the basis of an outward radial convection and inward diffusion along the interplanetary magnetic field (IMF) [2–5]. The balance between convection and diffusion generates an energy independent

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*Department of Physics, Aligarh Muslim University, Aligarh, India

anisotropic flow of cosmic ray particles from the 18-hour co-rotational direction. It has been observed from the critical analysis of diurnal variation calculated from ground based data, on a day to day basis [6–8] as well as on average basis for extended periods [9–12] that the simple co-rotational picture was inadequate to account for all the observed features, in particular, the shift in the diurnal phase to earlier hours for the outward field (±) of the solar polar magnetic field.

It is known that the northern magnetic pole of the sun was negative during 1964–68 (∓) and positive during 1972–79 (±), as it got reversed [13] during 1969–71. The reversal took place again in 1980 [14] and the northern magnetic pole of the sun became negative during 1981–86 (∓) after about 22 years.

The abrupt reversal in the phase of diurnal anisotropy is associated with the reversal of polarities of solar polar magnetic fields [15,16]. The perturbations in the heliospheric equatorial regions affect the galactic cosmic rays observed near the equator more effectively if the northern hemisphere heliospheric magnetic field is inward (–) than if it is outward (+) [17]. For high rigidity cosmic rays (50 GV and beyond), Erdos and Kota [18] proposed a theoretical model in which they pointed out that the origin of the change in the phase of solar diurnal anisotropy probably lies in the change of sense of particle drift in connection with the reversal of solar magnetic field.

Using the neutron monitor data, a significant change in the phase of diurnal anisotropy to earlier hours has been observed [9–12] after 1970. The diurnal phase continuously shifts to earlier hours as we go back to 1955 from 1957 whereas during this period, the amplitude of the diurnal anisotropy does not change significantly; generally the amplitude and phase of the solar diurnal anisotropy does not change on an yearly average basis during 1958–70 [2–5]. The sudden change in the direction of the solar diurnal anisotropies around 1970, presumably associated with the reversal of the solar poloidal field, has added a new dimension to the study of the physical process which is responsible for the solar modulation of cosmic ray intensity. Nagashima and Morishita [19] and Sharma and Yadav [20,21] suggested that the polarity of the solar magnetic field also plays a significant part in modulation of cosmic ray intensity. This aspect has been discussed extensively in the literature [16, 22–24].

In a series of papers, primarily by Jokipii, Levy and coworkers [3,4, 25–30], the importance of particle drift in cosmic ray propagation in the interplanetary space has been emphasized. They stress that the drifts dominate the motions of substantial portion of galactic cosmic ray particles and that the conventional picture of the cosmic ray transport in the heliosphere without drift, is inadequate.

It is shown from the cosmic ray data obtained during two complete sunspot cycles that the 22 year variation in the phase of the cosmic ray anisotropy exists [31]. This 22 year variation in the phase of the diurnal anisotropy is related to the solar magnetic field reversal.

We present here the results obtained for the phase of the diurnal anisotropy of the cosmic ray intensity using the data of neutron monitor at Deep-River (cut of rigidity Rc = 1.02 GV) for the different epoch's of solar activity cycles 20 and 21 : 1964–68 (∓) when the northern solar polar magnetic field of the sun was negative; 1972–79 (±) when it becomes positive and 1981–86 (∓) when again the northern solar polar magnetic field becomes negative nearly after 22 years. The results are discussed in the light of the drift model.

2. Analysis

To observe the dependence of the phase of the diurnal anisotropy on solar magnetic field polarity, the pressure corrected hourly neutron monitor data for Deep-River (which is facing the ecliptic plane with a narrow longitudinal broadening and has a suitable cone of acceptance for observing diurnal anisotropy) has been analysed for the three different periods (see Table 1), which were obtained by dividing the epoch's of solar activity cycles 20 and 21 into three groups of different solar magnetic field polarity : (i) 1964–68 (∓), when the northern solar polar magnetic field was negative, (ii) 1972–79 (±), when the northern solar magnetic field was positive and (iii) 1981–86 (∓) when again the northern solar polar magnetic field becomes negative nearly after about 22 years (Table 1). The amplitude and the phase of the

Table 1. Amplitude and phase of the diurnal anisotropy for three dipole orientations on different types of days.

Type of days	Period of the analysis		Polarity of the magnetic field	Diurnal anisotropy in space amplitude (%)	phase (hrs)	Drift notation
All days	1964–68	∓ ;	inward	0.40	18.00	qA < 0
	1972–79	± ;	outward	0.40	16.00	qA > 0
	1981–86	∓ ;	inward	0.30	18.00	qA < 0
Quiet days	1964–68	∓ ,	inward	0.40	18.00	qA < 0
	1972–79	± ;	outward	0.70	16.00	qA > 0
	1981–86	∓ ;	inward	0.40	18.00	qA < 0
Disturbed days	1964–68	∓ ;	inward	0.30	17.00	qA < 0
	1972–79	± ;	outward	0.40	16.00	qA > 0
	1981–86	∓ ;	inward	0.30	17.00	qA < 0

diurnal anisotropy are obtained after correcting the hourly data for long-term trend by subtracting the 24 hr moving average. The amplitude and the phase of diurnal anisotropy obtained at ground, are corrected for geomagnetic effects using the procedures established to obtain the anisotropy vector in space [32,33]. For energy independent spectrum ($\beta = 0$), the relative amplitude 0.8448 (in per cent) and the phase correction factor for geomagnetic effects 2.33 (in hours) are used in this analysis.

3. Results and discussion

The diurnal vectors in the interplanetary space for three periods of different solar dipole orientation (when all days in a year are taken into account) are shown in Figure 1. From Figure 1 it is clearly observed that the phase of the diurnal anisotropy shifts to earlier hours (16 hrs) during the period 1972–79 (±) as compared to that for the period 1964–68 (∓) and during 1981–86 ($\mp$) it again shifts towards the earlier position (1800 hrs) nearly after 22 years as observed in 1964–68 ($\mp$). For a better understanding of our results, the diurnal

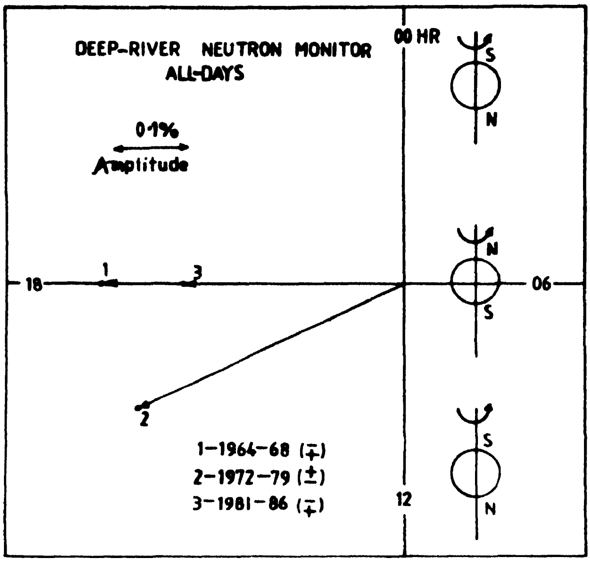

Figure 1. Diurnal vector (Amplitude and Phase) at Deep-River station in free space averaged over the periods for different solar dipole orientations (on the right is shown the sign of sun's dipole for these periods).

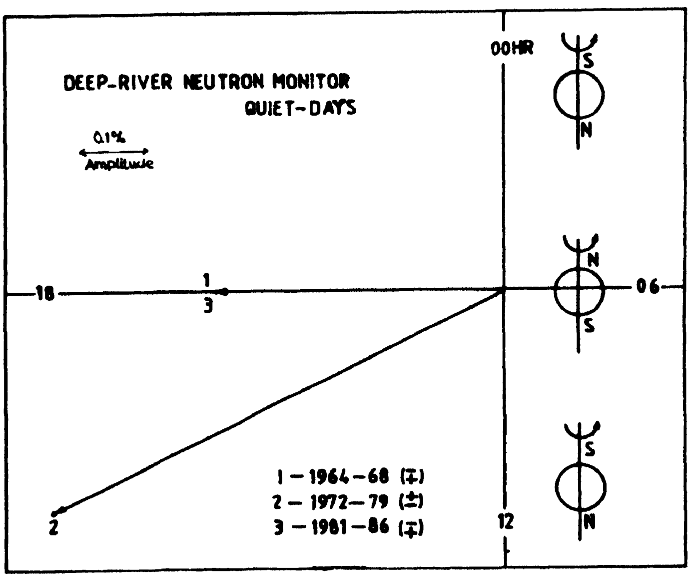

Figure 2. Diurnal vector (Amplitude and Phase) at Deep-River station in free space averaged over the periods for different solar dipole orientations (on the right is shown the sign of sun's dipole for these periods).

amplitude and phase were also calculated on geomagnetic quiet and disturbed days. The results are plotted on a harmonic dial plots (Figures 2 and 3) and are given in Table 1. From these results it is clear that even on quiet and disturbed days, the diurnal phase shifts to earlier hours during the periods 1972–79 (±) as compared to that for the periods 1964–68 (∓) and 1981–86 (∓). The results presented here, clearly indicate a 22 year periodicity in the phase of the diurnal anisotropy related with the 22 year solar magnetic cycle. Thus, the present results are in agreement with the findings of earlier investigators [25–31].

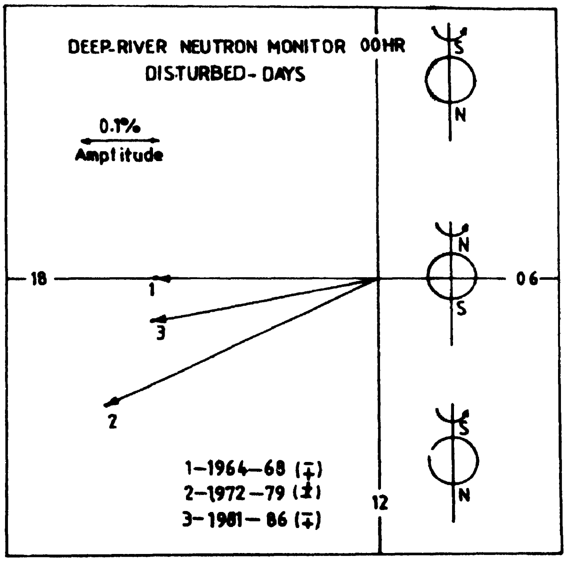

Figure 3. Diurnal vectors (Amplitude and Phase) at Deep-River station in free space averaged over the periods for different solar dipole orientations (on the right is shown the sign of sun's dipole for these periods)

The model calculation for high rigidity cosmic rays (≥ 50 GV) of Erodos and Kota [18] predicts the change of solar daily vectors in 1969. The effect of particle drift in Parker spiral model is such that the predominant access of cosmic rays to the inner solar system is either inward from the polar regions (when the northern polar magnetic field is positive) or inward along helio-equatorial region (when the northern magnetic field is negative) [25]. Erdos and Kota [18] noted that before 1969 the drift was such that the observed galactic particles had entered the solar system mainly at the helio-equatorial region, while particles had easier access to earth from polar regions after 1969 epoch. Thus the particles had less chance to experience several encounters with the rotating current sheet and this resulted in less effective co-rotation.

Our results obtained for low energy cosmic rays using the neutron monitor data for Deep-River (whose median primary rigidity of response 15 GV), are in good agreement with the theoretical results obtained for high rigidity (≥ 50 GV) particles and can be explained by the model proposed by them [18].

According to Parker spiral model, the effect of the particle drift is such that during 1964–68 and 1981–86, cosmic ray protons were expected to flow-in along the neutral sheet and flow-out at high latitudes. During 1972–79, cosmic ray protons were expected to flow into the heliosphere at high latitudes and flow out along the equatorial magnetic sheet. Energetic electrons should behave in the opposite way. Thus according to drift theories, during the periods 1964–68 ($^{N-}_{S+}$; qA < 0) and 1981–86 ($^{N-}_{S+}$; qA < 0), the inward drift and diffusive flow along the magnetic field near the equator balanced the outward convection anisotropy, leaving only the azimuthal component of the inward flow which appeared as a co-rotation anisotropy (1800 hrs). For the period 1972–79 ($^{N+}_{S-}$; qA > 0) the inner heliosphere near earth was populated more by drift down from high latitudes and the convection anisotropy was not as completely balanced; as a result the diurnal anisotropy shifts to earlier hours (Table 1). The present results provide observational evidences that the drift is important in the modulation of galactic cosmic rays.

Isenberg and Jokipii [34] suggested that since the drift velocities reverse their direction along with the magnetic field every 11 years, drift-effects can provide plausible explanation for 22 year periods in the transport properties, particularly the observed 22 year periodicity in the phase of the diurnal anisotropy.

4. Conclusions

The conclusions obtained from our systematic study of the diurnal variation during different periods of the solar polar magnetic field polarity are as follows :

1. The 22 year periodicity in the phase of the diurnal anisotropy which is also observed on magnetically quiet and disturbed days (Figures 1–3) is related with the 22 year solar magnetic cycle.
2. Phase of the diurnal anisotropy shifts to earlier hours for period 1972–79 ($^{N+}_{S-}$; qA > 0) when all days in a year are taken into consideration as well as on magnetically quiet and disturbed days. Our results are in general agreement with the curvature and gradient drift model.
3. Our results clearly show that the polarity of the solar polar magnetic field plays an important role in the modulation of cosmic rays.

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